Cold Survivable Distributed Motor Controller

Gary Bolotin
gary.s.bolotin@jpl.nasa.gov
Don Hunter, Chris Stell, Malcolm Lias,
Doug Sheldon, Malcolm Lias, Troy Gross

Jet Propulsion Laboratory
California Institute of Technology

The Problem We Are Trying to Solve

- **Conventional practice is to house actuator electronics in a protected, centralized, warm electronics box (WEB), requiring highly complex, point-to-point wiring to connect the drive and control electronics to the actuators and instruments, usually located at the system appendages.**

MSL Wiring Harness

Integration and Test

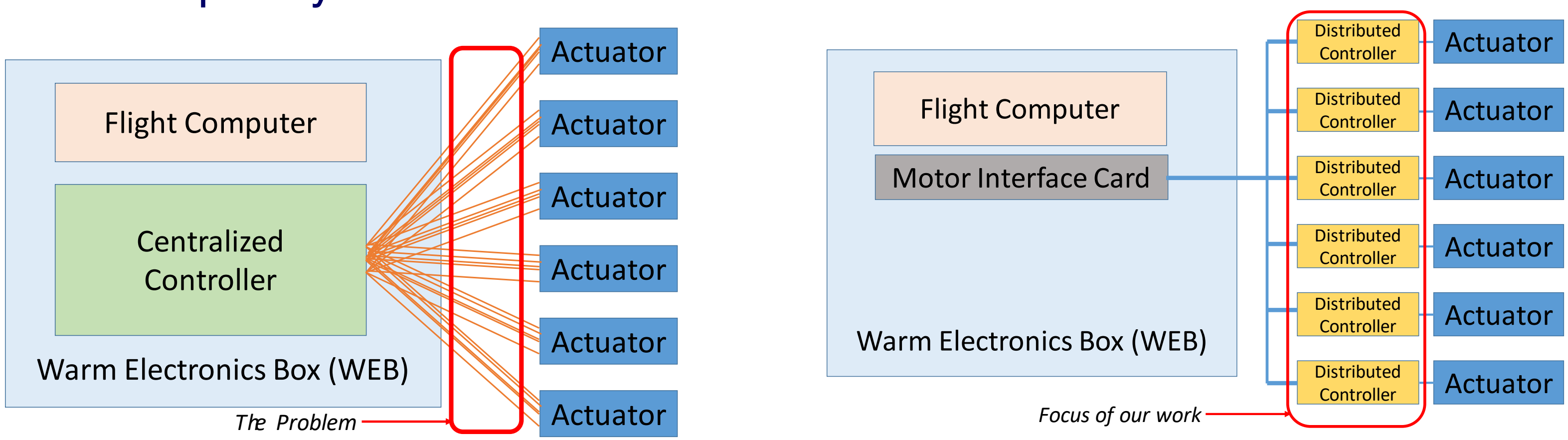
MSL's Robotic Arm

Illustration of cabling mass and complexity in current landed mission architectures across all subsystems and phases of development.
Bulky, not adaptable, heavy and unreliable

Overview 2 of 5

Our Solution: A Distributed System

- **We solve this problem by utilizing a distributed motor control (DMC) technology that will:**
  - minimize the dependency of the motor controller on the Warm Electronics Box(WEB)
  - eliminate the point-to-point wiring, and reduce the wire count by two orders of magnitude with concomitant savings in mass, cost and complexity.



Current state a practice: Point to point

Distributed Motor Control Electronics

Less complex, more adaptable, less mass

Our Solution: Benefits

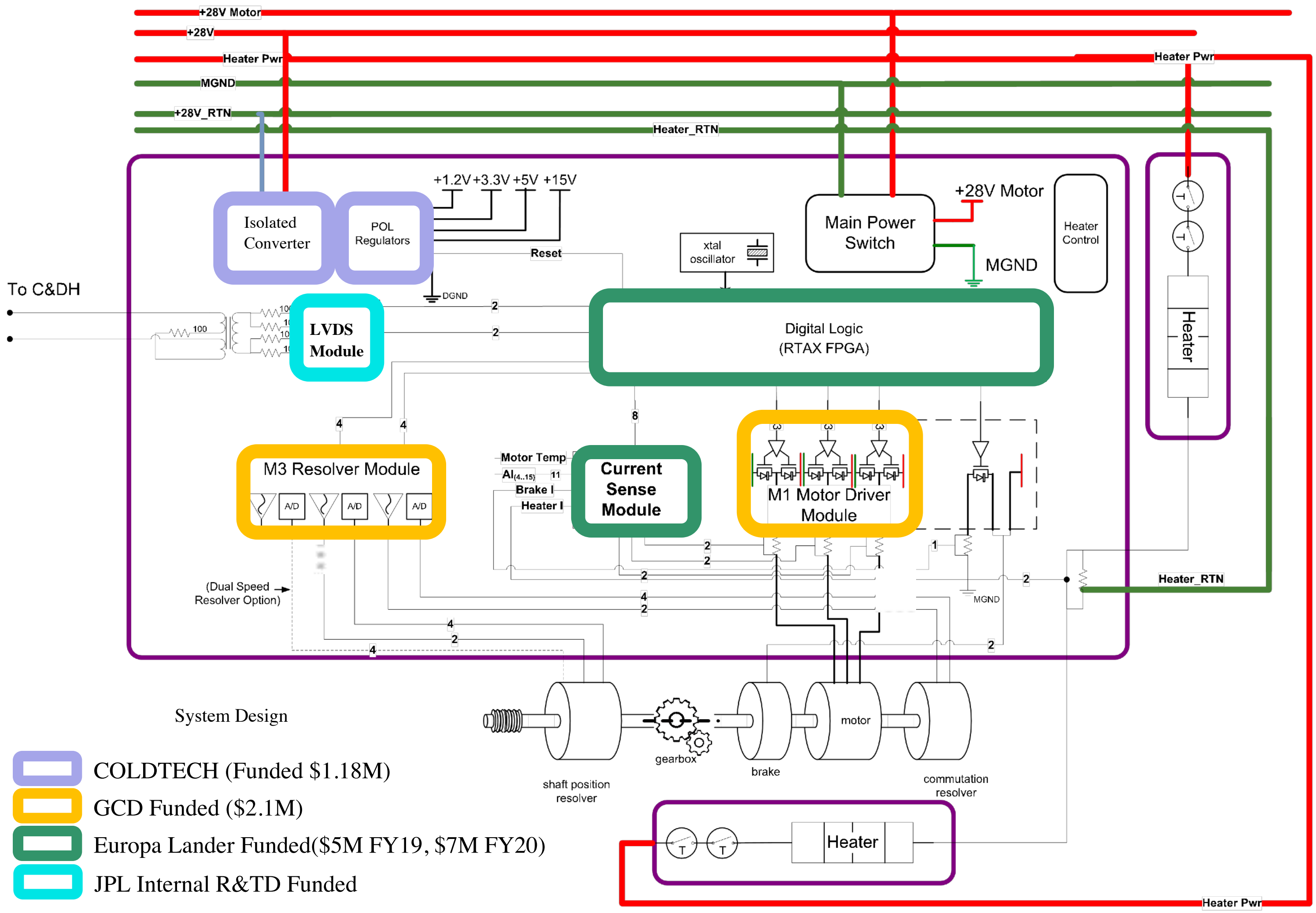
- **Historical JPL actuator cable mass and analysis of the benefits of our distributed architecture applied to the MSL mission**

Rover System	Mars Pathfinder	MER	MSL	MSL w/DMC (planned)	Benefit
Total Wiring Mass	1.4 Kg	10.4 Kg	52.7 Kg	37 Kg	15.6 Kg (90%) reduction in harness mass
Actuator Wiring Mass	0.35 Kg	3.0 Kg	17.4 Kg	1.8 Kg	

- **Additional benefits include:**
  - minimization of thermal losses by minimizing cables leaving the warm compartment.
  - greatly improved noise immunity, and reduced EMI which results in improved actuator control and repeatability.

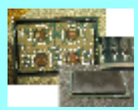
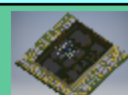
Enables either more science instruments or longer mission duration

CSDMC System Block Diagram



The CSDMC leverages prior investments from STMD, JPL IR&D, and Europa Lander

Module Development Heritage

Funding Source	Technology	Picture	Heritage	Function	Status
GCD	Motor Driver Module	 3.0cm x 3.0cm	GCD – Ultra Low Temperature Electronics	Power stage for driving motors	Prototype module testing complete
	Resolver Module	 3.5cm x 3.5cm	GCD – Ultra Low Temperature Electronics	Position sensing	Prototype module testing complete
RTD	Low Voltage Differential Switching (LVDS) Module	 1.5cm x 1.0cm	JPL Internal R&TD funding	Motor control card to central computer interface	Prototype module testing complete
EL	Current Sense Module	 1.7cm x 1.7cm	Europa Lander	Current and temperature sensing	Module design complete
CSDMC	Point of Load Regulator Module	 1.7cm x 1.7cm	NASA Coldtech	Circuit prototype complete Module design complete	Prototype module testing complete
	Isolated Converter Module	 1.7cm x 1.7cm	NASA Coldtech	Circuit design in progress	Module design complete

All components will be at TRL 5 by end of our 2 year effort and ready for infusion in the Europa Lander

CSDMC – Milestones

Planned Progress	Actual Progress
1. System Design	
1.1 Architecture and trade studies completed 5/17 1.2 CSDMC Detailed System Design 3/18	1.1 <u>Architecture and trade studies completed on 6/5/17</u> 1.2 <u>Detailed system design completed on 4/20/18</u>
2. Point of Load Regulator	
2.1 Prototype development completed 2.2 i3 Module design completed 12/17 2.3 Module fabrication completed 4/1/18 2.4 Module testing completed 6/1/18	2.1 <u>Prototype development completed on 11/1/17</u> 2.2 <u>Design completed on 12/13/17</u> 2.3 <u>First module delivered on 4/26/18</u> 2.4 <u>Initial module testing completed on 5/1/18</u>
3. Isolated Converter	
3.1 Compete electrical design 1/18 3.2 Isolated converter breadboard completed 3/18 3.3 Module design Completed 7/18 3.4 Module fabrication completed 9/18	3.1 <u>Design completed on 1/12/18</u> 3.2 <u>Testing completed on 3/1/18</u> 3.3 Module PDR scheduled for 10/17/18 3.4 Scheduled for 1/17/18
4. Cold Temperature Testing	
4.1 Component testing completed 3/18 4.2 Module testing completed 1/19	4.1 <u>Completed on 3/2/18</u> 4.2 Scheduled for 4/01/19

1.1 Architecture and Trade Studies

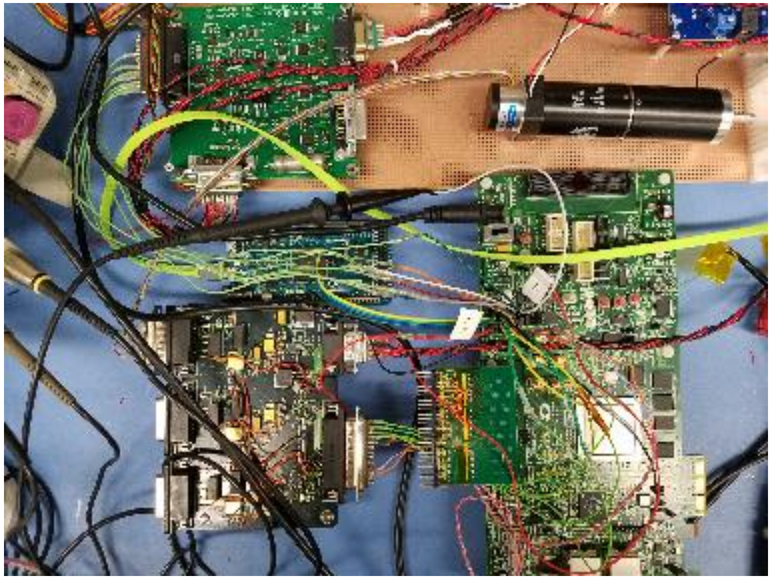
- Successful Concept System Design Review for the CSDMC held on 06/05/2017
- Agenda included:
  - Requirements
  - Area Study
  - Grounding scheme
  - Power Budget/ Power Conversion
- Review board included:
  - Dan Nakamura
  - Bill Whitaker
  - Luke Dubord
- Review passed, all actions addressed

This review represents the completion of the Architecture and Trade Studies milestone

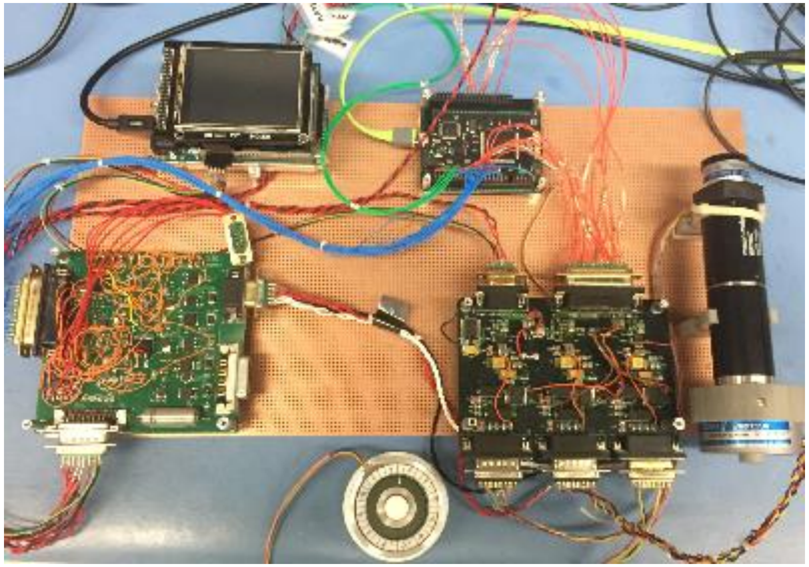
Technical Progress

1.2 Motor Control Demonstration

- **Two testbeds were constructed to show that our designs are able to play together and to allow for firmware and software development.**
- **Testbed incudes FPGA, Resolver, Motor Driver and Current sense module breadboards or modules**



Testbed #1



Testbed #2

We have completed a demonstration that shows all major pieces are working together.

Technical Progress
CSDMC – Milestones

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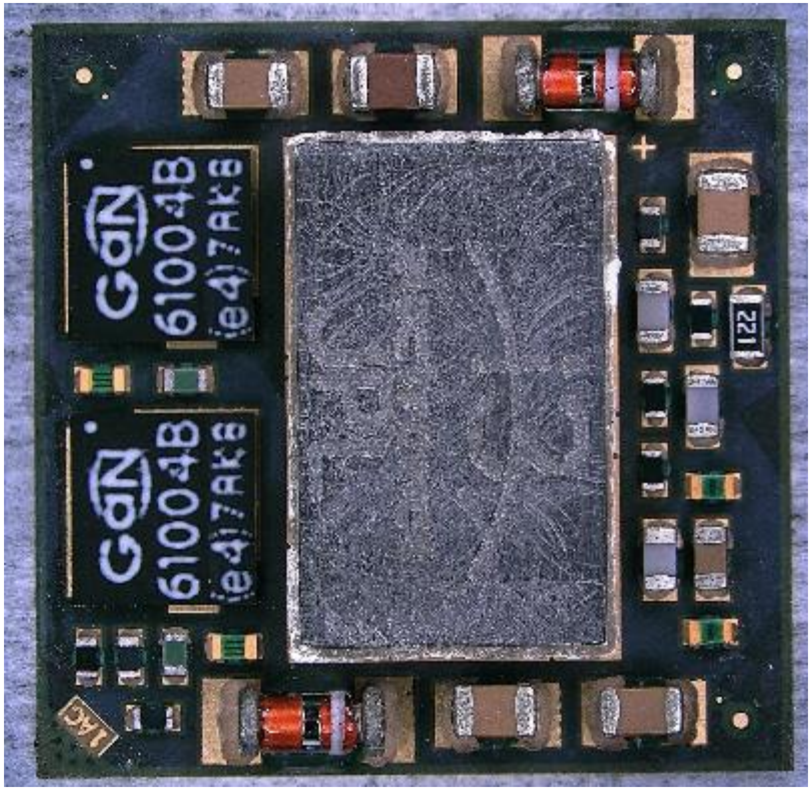
Point Of Load Module

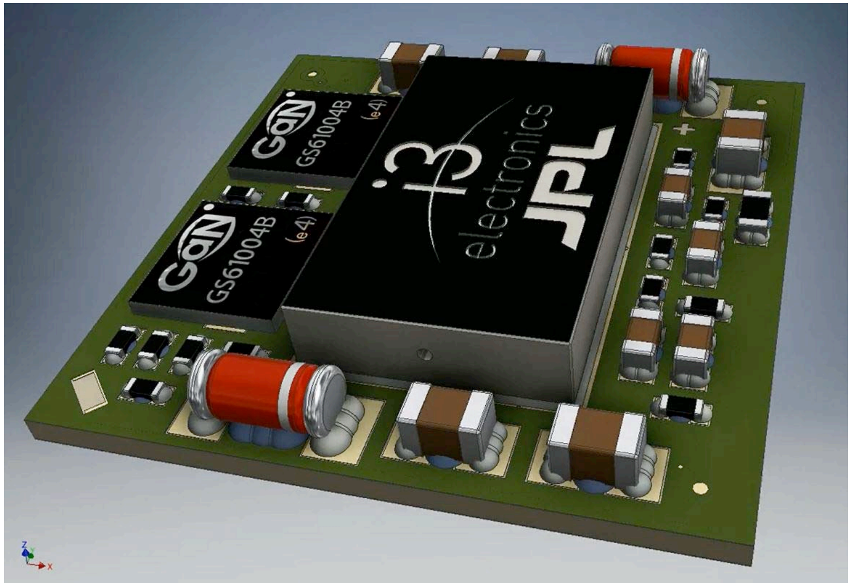


- Input Voltage: 3.3V to 36.0V
- Output Voltage[1,3]: 1.225V – 15.0v
- Output Current[2] up to 5A
- Efficiency > 90% (5V input, 3.3V 3.0A)
- Buck Converter Topology
- Adjustable switching frequency
- Input voltage under voltage protection
- 300KRAD Tolerant
- 1.7cm x 1.7cm compact size
- Storage temperature as low as -180C
- Over current protection
- Under voltage lockout

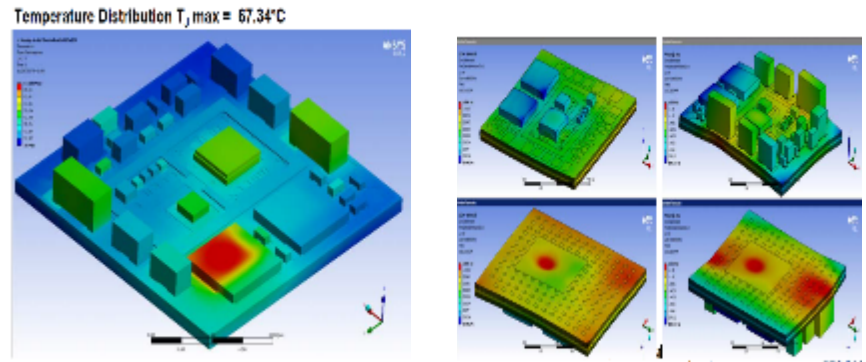
[1]Output voltage is user selectable.
[2]Output current is determined by external inductor and capacitor selection.
[3]Output voltages below 1.225V are possible with application of an external reference.

Our POL module represents the only integrated point of load regulation solution for Europa missions that require 300Krad radiation tolerance.
Applying this module to the industry standard RAD750 would cut its power consumption by 25%.

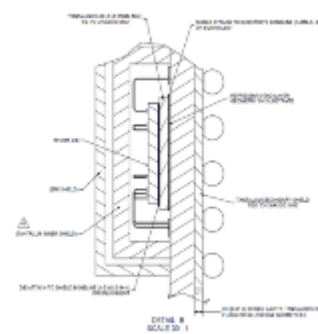
Technical Progress
Point Of Load Module Design



Point of Load Module



Thermal and Mechanical Analysis Complete



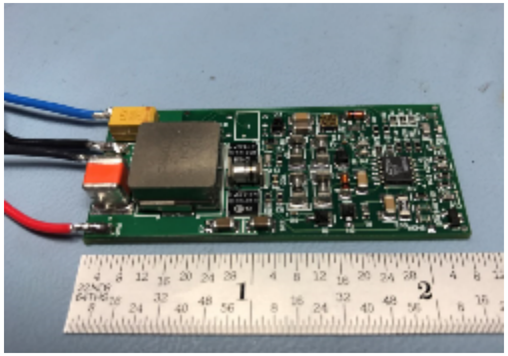
POL Module shield design is complete
Radiation analysis is complete

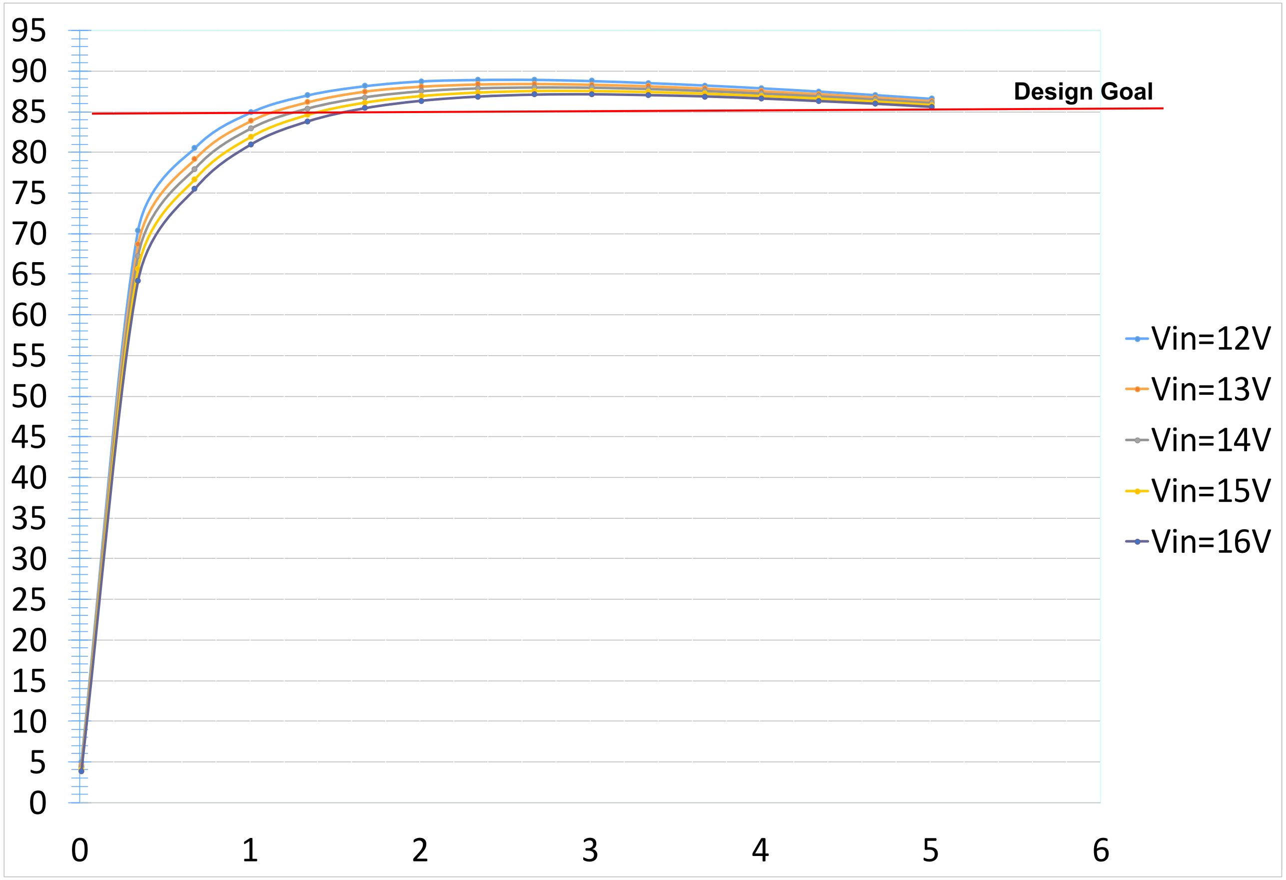
<u>POL Module design is complete</u>. A module PDR was held on 12/13/17.
Passed the PDR and all actions have been addressed.

Technical Progress

Point Of Load Module Active Performance

- Circuit is 5% less efficient than predicted.





Module performance exceeds design goal of 85% efficiency at Vin = 15.0v